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Extended Summaries
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The following are extended summaries based on papers presented at the 42nd Hungarian Plant Protection Days Meeting, organised by the Hungarian Agricultural Society, the Hungarian Academy of Sciences, the Hungarian Ministry of Agriculture and the Plant and Soil Protection and Soil Conservation Station of Budapest and held in Budapest, Hungary on 27/28 February, 1996. They are entirely the responsibility of the authors and do not necessarily reflect the views of the Editorial Board of Pesticide Science.

A Survey of the Insecticide Resistance Status of the Colorado Potato Beetle, *Leptinotarsa decemlineata*, in Hungary between 1987 and 1991

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The Colorado potato beetle (CPB) (*Leptinotarsa decemlineata* Say) has become the most serious insect pest in potato as a result of frequent applications of insecticides. Of the active ingredients of the 37 insecticide products registered for use against CPB in Hungary, one is an organochlorine compound, seven are organophosphorus compounds, two are carbamates, three are nereistoxin analogues, nine are pyrethoids and three are benzoylureas. Recently, the biological control agent *Bacillus thuringiensis* Berliner has also been introduced. Six products, four organophosphates, one organochlorine and one carbamate, are also available for soil treatment.

After CPB became established in Hungary in the late 1940s, DDT and other organochlorines were used for its control. Due to problems with residues and/or some resistance, organochlorines were replaced by organophosphorus compounds and then with carbamate insecticides in the 1970s. At the end of the same decade, pyrethoids, and subsequently a nereistoxin analogue, were introduced for CPB control. The registration of benzoylureas and biological control agents represents the latest progress, widening the choice of means appropriate for the chemical control and resistance management of CPB. This beetle has developed varying levels of resistance to every insecticide used for its control within a relative short time period.[1]

Pyrethroids (e.g. deltamethrin, cypermethrin, alpha- and beta-cypermethrin, lambda-cyhalothrin and esfenvalerate) have been used extensively against CPB in Hungary during the last 15 years. Apart from a few sporadic warnings about reduced efficacy of pyrethroid treatments, there has been no evidence for a considerable level of pyrethroid resistance in Hungary until recently. However, because of their highly specific mode of action and the possible occurrence of cross-resistance, there is a high risk of development of resistance to these compounds in CPB. Because very little information was available on the insecticide resistance status of CPB in Hungary, a nationwide resistance survey was carried out between 1987 and 1991. To establish any relationship between the results of the bioassays and field control efficacy, the program consisted of initial laboratory tests followed by small-plot field trials when the laboratory bioassay indicated high phenotypical tolerance. Beta-cypermethrin was used regularly to check the sensitivity of field populations in small-plot trials. The object of this survey was not only to monitor the spatial and temporal variation of the resistance level in CPB populations to several insecticides but also to estimate critical LD_{50} values above which treatments fail to give appropriate control ('threshold' LD_{50}, according to Denholm *et al.*[2]). Samplings and small-plot field trials were done by entomologists of Plant Protection Stations located in various regions of Hungary. Field trials were carried out using a completely randomised block arrangement of four parallel 25-m^2 plots each containing four parallel rows, the test material being sprayed at 300 litre ha^{-1}. Efficacy was assessed at 2, 5 and 10 days after treatment using the Henderson–Tilton formula

$$\text{Efficacy} = 100(1 - A_1B_2/A_2B_1)$$

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TABLE 1
Variation in LD_{50} values of Insecticides for Fourth Instar and Adult of Colorado Potato Beetle Populations Collected in Hungary during the Period of 1987–1991

	Larva (μg per larva)					Adult (μg per beetle)				
	n^a	$LD_{50}{}^b$	SEM[c]	Min.[d]	Max.[e]	n^a	$LD_{50}{}^b$	SEM[c]	Min.[d]	Max.[e]
Permethrin										
1987	8	1.80	0.35	0.82	3.47	11	3.71	0.49	1.44	6.09
1988	16	3.12	0.23	1.59	5.31	17	5.04	0.48	2.59	8.85
1989	7	2.10	0.48	0.81	4.22	8	3.53	0.40	2.36	5.96
1990	19	2.20	0.39	0.16	8.09	30	7.43	0.87	1.44	>20
1991	23	13.59	1.48	3.30	>20	24	11.92	0.88	3.55	>20
Cypermethrin										
1987	8	0.10	0.014	0.07	0.19	13	0.18	0.02	0.05	0.33
1988	16	0.12	0.006	0.06	0.15	17	0.19	0.01	0.12	0.31
1989	7	0.09	0.013	0.05	0.13	8	0.15	0.01	0.10	0.22
1990	19	0.09	0.012	0.04	0.23	30	0.31	0.05	0.05	1.52
1991	23	0.22	0.099	0.05	2.37	24	0.40	0.05	0.07	1.19
Beta-cypermethrin										
1987	8	0.05	0.005	0.03	0.08	14	0.08	0.009	0.03	0.15
1988	16	0.04	0.005	0.01	0.10	17	0.08	0.007	0.02	0.14
1989	7	0.04	0.007	0.01	0.06	8	0.07	0.006	0.04	0.09
1990	19	0.03	0.004	0.02	0.07	30	0.12	0.014	0.02	0.35
1991	23	0.05	0.005	0.02	0.12	24	0.17	0.019	0.04	0.36
Quinalphos										
1987	8	0.37	0.05	0.23	4.78	13	1.08	0.33	0.19	3.80
1988	16	4.27	1.95	0.20	>20	17	3.99	1.60	0.52	>20
1989	7	2.02	0.61	0.67	4.94	8	4.03	1.39	0.86	12.39
1990	19	1.44	0.54	0.07	10.85	30	2.78	0.37	0.66	7.94
1991	23	1.21	0.21	0.30	4.93	24	7.74	1.63	0.91	>20
Carbofuran										
1987	6	0.49	0.11	0.20	0.99	10	0.76	0.18	0.24	1.84
1988	16	1.45	0.39	0.34	5.88	17	3.19	1.54	0.19	>20
1989	7	1.02	0.25	0.46	2.37	8	3.55	1.19	0.54	9.63
1990	19	0.94	0.16	0.31	2.77	30	4.72	0.99	0.43	>20
1991	23	1.60	0.15	0.74	3.17	24	5.21	0.84	0.87	14.70
Bensultap										
1987	—[f]	—	—	—	—	—	—	—	—	—
1988	16	1.07	0.16	0.21	2.05	17	13.10	1.52	2.32	20.09
1989	7	1.07	0.12	0.52	1.52	8	13.51	2.59	5.22	20.71
1990	19	1.09	0.16	0.31	2.64	30	18.95	1.29	0.39	32.74
1991	23	2.09	0.22	0.93	5.48	24	17.16	0.96	4.60	20.67

[a] Number of tested populations.
[b] Mean LD_{50} values for given year.
[c] Standard error of mean.
[d,e] Minum and maximum values of LD_{50}.
[f] Not used in this year.

where A_1 and A_2 are the numbers of living insects on treated plots after and before treatment and B_1 and B_2 are the numbers of living insects on untreated control plots after and before treatment, respectively.

A total of 73 as L4 instar and 93 adult CPB populations from both the first and second generations were collected from each potato field. The details of cultivation routine and the other pesticides than test materials applied before the collection were recorded. Quinalphos, carbofuran, permethrin, cypermethrin, beta-cypermethrin and bensultap were used as representatives of their groups. The individuals of sampled populations were subjected to dose–response bioassay according to the topical method recommended by FAO[3] as has been described previously,[4] and mortality was assessed at 24 h after treatment. Two repli-

Fig. 1. Distribution of LD_{50} values of different insecticides in field-collected populations of (A) fourth-instar larvae and (B) adult Colorado Potato Beetle. PERM: Permethrin, CYP: Cypermethrin, BETA-CYP: Beta-Cypermethrin, QUIN: Quinalphos, CARB: Carbofuran, BENS: Bensultap. Class intervals were determined by the following multiplier factors of mean LD50 values: 0.125–0.25; 0.25–0.5; 0.5–1; 1–2; 2–4; 4–8.

cate sets of three to six doses, giving a range of 0–100% mortality, were used and the median lethal dose (LD_{50} expressed in ng per insect) was determined by probit-analysis for each set of data. Due to the lack of a standard susceptible CPB strain, the mean ($\pm$SEM), minimum and maximum LD_{50} values of the tested compounds in each year were used to follow the alterations in susceptibility of collected populations (Table 1). As a rule, the larvae tended to be more sensitive than the adults to every insecticide. This difference was very pronounced for bensultap which proved to be ineffective against adults.

In spite of the large annual variation of LD_{50} values, an increasing trend towards tolerance of CPB populations to the treatments was generally detected. Accordingly, the highest LD_{50} values for every insecticide were obtained in the last year of the survey (1991), except for quinalphos. Although the tested pyrethroids are closely related, they showed a large difference in this respect. The sudden significantly increased mean LD_{50} of permethrin in 1991 indicates a considerable reduction in the sensitivity of surveyed CPB populations to this compound; extremely tolerant populations ($LD_{50} >$ 200 000 ng per insect) appeared among both larvae and adults, indicating a growing risk of resistance to this compound. The maximum LD_{50} values of cypermethrin also increased considerably both in larvae and adults during the course of the study. Small range and sporadic variations, but not extremely high LD_{50} values, were detected for beta-cypermethrin in larvae and

adults during the whole period, indicating a lower resistance risk with this compound than with permethrin and cypermethrin. This was confirmed by a field trial on populations of adults which were most tolerant to beta-cypermethrin ($LD_{50} = 0.36$ μg per beetle; Table 1) collected in Jákó (Somogy County in the southwest region of Hungary; sampling date 16 July 1991). Recommended doses of beta-cypermethrin (15 g AI ha^{-1}) and quinalphos (375 g AI ha^{-1}) gave more than 97% control even at 10 days after treatment.

The tolerance distributions of collected larval and adult populations to tested insecticides are shown in Figs 1A and 1B, respectively. Again, striking differences occur between individual pyrethroids. In contrast to permethrin and cypermethrin, no larval or adult population was found with four-fold greater tolerance than the modal response to beta-cypermethrin, in fairly good agreement with earlier data obtained for the housefly, for which about a four-fold or greater increase in modal response was needed to get the failure threshold for deltamethrin.[2] Our results suggest that characteristic differences in resistance risk can exist between pyrethroids. However, since the resistance evolution is a potential threat in CPB, the continuous monitoring of resistance status is needed to obtain baseline toxicity data, to check for significant differences and to assess the cross-resistance pattern.

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